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Animal biodiversity: An introduction to higher-level classification and taxonomic richness

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Abstract

For the kingdom Animalia, 1,552,319 species have been described in 40 phyla in a new evolutionary classification. Among these, the phylum Arthropoda alone represents 1,242,040 species, or about 80% of the total. The most successful group, the Insecta (1,020,007 species), accounts for about 66% of all animals. The most successful insect order, Coleoptera (387,100 species), represents about 38% of all species in 39 insect orders. Another major group in Arthropoda is the class Arachnida (112,201 species), which is dominated by the mites and ticks (Acari 54,617 species) and spiders (43,579 species). Other highly diverse arthropod groups include Crustacea (66,914 species), Trilobitomorpha (19,606 species) and Myriapoda (11,885 species). The phylum Mollusca (117,358 species) is more diverse than other successful invertebrate phyla Platyhelminthes (29,285 species), Nematoda (24,783 species), Echinodermata (20,509 species), Annelida (17,210 species) and Bryozoa (10,941 species). The phylum Craniata, including the vertebrates, represents 64,832 species (for Recent taxa, except for amphibians): among these 7,694 described species of amphibians, 31,958 species of "fish" and 5,750 species of mammals.

Introduction

Discovering and describing how many species inhabit the Earth remains a fundamental quest of biology, even when we are entering the "phylogenomic age" in the history of taxonomy. With so many important issues facing us—invasive species, climate change, habitat destruction and loss of biodiversity in particular, the need for authoritative taxonomic information is higher than ever. *Zootaxa* has been a major force in describing world's biodiversity in the last 10 years (Zhang 2011a). Most of the papers published in *Zootaxa* are descriptions of new taxa and taxonomic revisions interesting mainly to specialists. However, to reach a broader readership, we present, in this special volume, basic taxonomic data (classifications and diversity estimates) that are very important to the any user of biodiversity information. Extensions of results of taxonomic research to users, not only other taxonomists, but also all others, are important to achieve a greater impact for taxonomy.

The idea of this special volume was conceived in 2010—The International Year of Biodiversity. This volume is intended to be a collaborative effort by hundreds of taxonomists, each contributing a section on his/her group to the overall outline of the current, most-accepted taxonomy of the animal kingdom. The bulk of the volume will be a series of linear sequences of higher taxa (living and fossil, the latter to be indicated by a dagger (†)) from kingdom to family in a Linnaean hierarchy, using valid names following the International Code of Zoological Nomenclature. For each family, the best estimate of the number of described genera and species in the world is provided by specialists of the group. We want to present two types of important taxonomic information—how many species have been described and how they are classified—to the users of biodiversity information in an easily accessible volume, which is published for open access without cost to contributors.

Results

General account

Over 100 taxonomists contributed 43 outlines, some for phyla, some for classes and some for orders (see the outline below for notes and references to various outlines in this volume). About a quarter of the phyla were covered, with many gaps to be filled by specialists in future editions. During preparation of the volume, it quickly became evident that for many groups, there are different classifications for fossil and Recent taxa, and there is little dialogue among taxonomists working on Recent species and those on fossil. A good example is the outline on Porifera by Hooper *et al.* (2011), who tried to bring these together. The diversity estimates for many groups are deficient in fossil counts, and the total is therefore underestimated. We invite taxonomists working on both Recent and fossil taxa to joint effects in providing a more complete outline of animal classification in future editions.

For the kingdom Animalia, 1,552,319 species have been described in 40 phyla (see the list below). Among these, the phylum Arthropoda alone represents 1,242,040 species, or about 80% of the total. The most successful group, the Insecta (1,020,007 species), accounts for about 66% of all animals, or 82% of arthropods. The most successful insect order, Coleoptera (387,100 species), represents about 38% of all species in 39 insect orders. Another major group in Arthropoda is the class Arachnida (112,201 species), which is dominated by the mites and ticks (Acari 54,617 species) and spiders (43,579 species). Other highly diverse arthropod groups include Crustacea (66,914 species), Trilobitomorpha (19,606 species) and Myriapoda (11,885 species).

The phylum Mollusca (117,358 species) leads, by a significant margin, among other invertebrate phyla in diversity. Significant groups include: Platyhelminthes (29,285 species), Nematoda (24,783 species), Echinodermata (20,509 species), Annelida (17,210 species) and Bryozoa (10,941 species).

The phylum Craniata, including the vertebrates, represents 64,832 species (for Recent taxa, except for amphibians). Blackburn & Wake (2011; this volume) presented a new consensus classification for amphibians, with an estimate of 7,694 described species. Eschmeyer & Fong (2011) summarised data from the "Catalog of Fish" (31,958 species). Wilson & Reeder (2011, this volume) updated their list of 5,750 species of Mammalia.

An evo-Linnaean classification of animal phyla

There are different schemes of presenting a classification or translating a phylogeny into a classification. Without any phylogenetic information, the simplest way is to list all phyla by alphabetical order. The Catalogue of Life[1], for example, lists animal phyla alphabetically, with complete loss of phylogenetic information. Traditionally, taxonomists also list taxa of equal rank using a self-chosen sequence (if not alphabetical), with basal taxa listed first and most derived one at the end. With explicit phylogentic information available, Hennig (1965) showed that a linear sequence using a combined successive alphabet/number prefix can fully represent phylogentic relationships. A cladogram can be presented in a hierarchy with inclusions of less includive members into sets of more inclusive taxa, which are given higher ranks (e.g., Hennig 1966: fig. 18 and also Dubois 2006: fig. 3). Wiley (1979) proposed an annotated Linnaean hierarchy, with comments on natural taxa and competing systems, and this is applied, for example, to the list of Diptera in a hierarchical sequence (Pape *et al.* 2011, this volume), with taxa arranged more or less in phylogenetic sequence from the primitive (oldest) to the most advanced (youngest) taxa, and some clades not ranked. I, however, found the latter not the best way, in terms of both nomenclatural aspects and also the level of details in providing phylogentic information at the level of terminal taxa.

The phylogeny of the animal phyla is in a flux (Edgecombe *et al.* 2011), with five competing hypotheses among five major basal taxa: Ctenophora, Porifera, Placozoa, Cnidaria and Bilateria. Thus any nomenclature and classifications at the levels of subkingdom to superphylum will be unstable due to the problems at the most basal positions. Supporters of the PhyloCode (De Queiroz & Gauthier, 1992) tend to name all heirarchical nodes of a tree and the shortage of Linnaean ranks to deal with this is one reason for the rankless systems of nomenclature and their uses in classification. However, not all nodes of such trees need to be named (Dubois 2006, 2007), and nomenclatural ranks can be used consistently to express the positions of taxonomic categories in a hierarchical classification. Herein, I used a new method to present the "evo-Linnaean" classification of animal phyla: (1) The essence of this system is to use commonly used Linnaean ranks as much as possible and combine each of these ranks with a successive numbering system[2]. This system can easily cope with all levels in a phylogenetic tree.

1. Catalogue of Life: 5th December 2011 http://www.catalogueoflife.org/ (accessed on 18 Dec. 2011)

Dubois (2006) proposed a detailed standard nomenclatural hierarchy which altogether allows for 209 potential ranks by using additional prefix beyond what is commonly used (e.g. super, sub and infra-). However, between two major ranks (e.g. Kingdom and Phylum), the number of ranks is limited and not sufficient to express all possible levels of relationships among phyla. (2) I refer to this as the "evo-Linnaean" classification to indicate that this classification aims at reflecting evolutionary relationship as much as possible to set it apart from the traditional Linnaean classification, which has a typological connotation. Taxa should be arranged from basal-most to the most derived group following the relationship in a chosen hypothesis or reference tree. (3) New names for hypothesised taxa that lack consistent support are minimised. (4) To follow, as much as possible, the Codes of nomenclature. Although, names of taxa above the family-group are not fully regulated in the ICZN, it is a good practice to use existing names for the same taxa (Dubois 2006). This system is also applied to an evo-Linnaean classification of Arthropoda (Zhang, 2011b, this volume).

Kingdom **Animalia** Linnaeus, 1758 (1,552,319 species; of which †24,659)[3]

Phylum 1 **Ctenophora** Eschscholtz, 1829 (242 species)[4]

Phylum 2.1 **Porifera** Grant, 1826 (8,346 species)[5]

Phylum 2.2 1 **Placozoa** Grell, 1971 (1 species)

Phylum 2.2.2.1 **Cnidaria** Hatschek, 1888 (10,105 species)[6]

Phylum 2.2.2.2 **Myxozoa** Grassé, 1970 (2,402 species[7]) [8]

Phylum 2.2.2.3.1.1 **Xenoturbellida** Westblad, 1949 (2 species)[9]

Phylum 2.2.2.3.1.2 **Acoelomorpha** Ehlers, 1985 (393 species)

Phylum 2.2.2.3.2.1 **Orthonectida** Giard, 1877 (43 species)[10]

Phylum 2.2.2.3.2.2 **Rhombozoa** van Beneden, 1876 (123 species)[11]

Phylum 2.2.2.3.3.1.1.1 **Cephalochordata** Owen, 1846 (33 species)[12]

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2. The International standard ISO 2145, which defines a typographic convention for the "numbering of divisions and subdivisions in written documents". It applies to any kind of document, including manuscripts, books, journal articles, and standards. It is commonly used in Table of Contents of books to express hierarchical structure. For example, Rasnitsyn & Quicke (2002) used the numbering system in the table of contents (pages vii–viii) to express the phylogenetic tree of Insecta (page 2).
3. This evo-Linnaean classification of animal phyla general follows consensus phylogenetic relationships summarised in Edgecombe *et al.* (2011). The poorly known extinct phylum †Trilobozoa is of uncertain placement. Only Recent species were counted for many insect orders and all of Myriapoda; most vertebrates and many invertebrate phyla; so the total number of species should be considered incomplete, as diversity of fossil taxa is underestimated.
4. Ctenophora was placed as sister group to the remaining animals (Porifera (Placozoa (Cnidaria, Bilateria))) in phylogenomic analyses by Dunn *et al.* (2008) and Hejnol et al. (2009). Diversity estimate based on WoRMS (2011). Ctenophora. In: Nicolas Bailly (2011). FishBase. Accessed through: World Register of Marine Species at http://www.marinespecies.org/aphia.php?p=taxdetails&id=1248 on 2011-12-18.
5. Hooper *et al.* (2011, this volume), but number of fossil species unknown, although an attempt was able to integrate the classification of Recent and fossil Porifera.
6. Daly *et al.* (2007) included 5 classes: (1) Anthozoa with an estimate of 7,500 extant species, now updated by Crowther (2011, this volume) to 6,142 species; (2) Cubozoa 36 species, here updated to 42 species; (3) Hydrozoa 3500 species, updated to 3,643 species; (4) Scyphozoa 216 species, updated by 228 species (all updates by Zhang based on Zoological Record for new species since 2008); (5) Staurozoa 50 species.
7. Based on Lom & Dykova (2006), with updates of new species described from 2006 using *Zoological Record*.
8. Zrzavy *et al.* (1998) placed it within Cnidaria based on morphological and 18S ribosomal DNA evidence, recently, Evans et al. (2010), using phylogenomic and ribosomal data sets, showed existence of two relatively stable placements for myxozoans: within Cnidaria or the alternative hypothesis at the base of Bilateria. Cnidarian taxonomists currently do not consider myxozoans as cnidarians (Daly et al. 2007).
9. See Tyler & Schilling (2011, this volume), who treat this phylum as a subphylum of Xenacoelomorpha, following Philippe *et al.* (2011), who proposed the name Xenacoelomorpha for Xenoturbellida + Acoelomorpha.
10. Edgecombe *et al.* (2011) recognised two subgroups of Mesozoa, Orthonectida and Rhombozoa, as phyla but did not include them in the phylogentic tree. The placement of Mesozoa here follows Noordijk *et al.* (2010). Diversity estimates based on Furuya, H & van der Land, J. (2011). Orthonectida. Accessed through: World Register of Marine Species at http://www.marinespecies.org/aphia.php?p=taxdetails&id=14220 on 2011-12-17.
11. Diversity estimates based on WoRMS (2011) Rhombozoa. Accessed through: World Register of Marine Species at http://www.marinespecies.org/aphia.php?p=taxdetails&id=14219 on 2011-12-17.
12. Based Chapman (2009).

Phylum 2.2.2.3.3.1.1.2.1 **Tunicata** Lamarck, 1816 (2,792 species) [13]
Phylum 2.2.2.3.3.1.1.2.2 **Craniata** Linnaeus, 1758 (64,832 species)[14]
Phylum 2.2.2.3.3.1.2 1 **Echinodermata** (20,509 species; of which †13,000)[15]
Phylum 2.2.2.3.3.1.2.2 **Hemichordata** Bateson, 1885 (120 species)[16]
Phylum 2.2.2.3.3.2.1 **Chaetognatha** Leuckart 1854 (186 species; of which †7)[17]
Phylum 2.2.2.3.3.2.2.1.1 **Nematoda** Cobb, 1932 (24,783 species, of which †10)[18]
Phylum 2.2.2.3.3.2.2.1.2 **Nematomorpha** Vejdovsky, 1886 (351 species)[19]
Phylum 2.2.2.3.3.2.2.2 **Tardigrada** Doyère, 1840 (1,157 species)[20]
Phylum 2.2.2.3.3.2.2.3.1 **Onychophora** Grube, 1853 (182 species, †3)[21]
Phylum 2.2.2.3.3.2.2.3.2 **Arthropoda** von Siebold, 1848 (1,242,040 species; †6,182)[22]
Phylum 2.2.2.3.3.2.2.4.1 **Priapulida** Théel, 1906 (19 species)[23]
Phylum 2.2.2.3.3.2.2.4.2 **Loricifera** Kristensen, 1983 (30 species)[24]
Phylum 2.2.2.3.3.2.2.4.3 **Kinorhyncha** Reinhard, 1881 (179 species)[25]
Phylum 2.2.2.3.3.2.3.1.1 **Bryozoa** Ehrenberg, 1831 (10,941 species; of which †5,455)[26]
Phylum 2.2.2.3.3.2.3.1.2.1 **Entoprocta** Nitsche 1869 (169 species)[27]
Phylum 2.2.2.3.3.2.3.1.2.2 **Cycliophora** Funch & Kristensen, 1995 (2 species)[28]
Phylum 2.2.2.3.3.2.3.2.1.1 **Annelida** Lamarck, 1809 (17,210 species)[29]
Phylum 2.2.2.3.3.2.3.2.1.2 **Spincula** Rafinesque, 1814 (1,507 species)[30]
Phylum 2.2.2.3.3.2.3.2.1.3 **Echiura** Newby, 1940 (236 species)[31]
Phylum 2.2.2.3.3.2.3.2.2 **Mollusca** Linnaeus, 1758 (117,358 species)[32]
Phylum 2.2.2.3.3.2.3.2.3 **Nemertea** Schultze, 1851 (1,200 species)[33]
Phylum 2.2.2.3.3.2.3.2.4.1 **Brachiopoda** Duméril, 1806 (443 species)[34]
Phylum 2.2.2.3.3.2.3.2.4.2 **Phoronida** Hatschek, 1888 (10 species)[35]

13. Also as Urochordata. Diversity estimates based on Chapman (2009) with updates.
14. Total for Recent taxa, except for amphibians; (1) 31,958 "fish" species (Eschmeyer & Fong, 2011, this volume); (2) 7,694 species of Amphibia (Blackburn & Wake , 2011; this volume); (3) 5,750 of species of Mammalia (Wilson & Reeder 2011, this volume); (4) 9,990 species of birds (Chapman 2009); (5) 9,413 species of reptiles based on http://www.reptile-database.org/db-info/SpeciesStat.html (1 August update); it should be noted that this database listed 327 species of Testudines, whereas only 317 species of Testudines in Fritz (2011, this volume).
15. Updated from Pawson (2001), who estimated 7,000 living and 13,000 fossil species.
16. Based on Chapman (2009) with updates.
17. Based on Noordijk *et al.* (2010) with updates of 2010 and 2011 new names in Zoological Record.
18. See Hodda (2011, this volume).
19. Based on Poinar (2007) with updates.
20. Guidetti & Bertolani (2011, this volume): Heterotardigrada 444 species, Eutardigrada 712 species, Mesotardigrada 1 species.
21. See Mayer & Oliveira (2011, this volume).
22. See Zhang (2011b, this volume).
23. After Neuhaus, B. (2011). Priapulida. Accessed through: World Register of Marine Species at http://www.marinespecies.org/aphia.php?p=taxdetails&id=101063 on 2011-12-17.
24. Based on Chapman (2009) & Gad (2009a,b).
25. Based on Neuhaus *et al*. (2011).
26. Phil Bock (personal communication, 17 Aug. 2011).
27. Also as Kamptozoa; diversity estimates based on WoRMS (2011) Entoprocta. Accessed through: World Register of Marine Species at http://www.marinespecies.org/aphia.php?p=taxdetails&id=1271 on 2011-12-09.
28. Based on Funch & Kristensen (1995), Obst et al. (2006).
29. Based on Chapman (2009) with updates of 2009–2011 new names in Zoological Record.
30. There are recent evidence that this phylum, along with, Echiura and Siboglinidae, is part of Annelida (Struck et al. 2011). Diversity estimate based on WoRMS (2011). Sipuncula. In: Saiz, J. (2011) World Sipuncula database. Accessed through: World Register of Marine Species at http://www.marinespecies.org/aphia.php?p=taxdetails&id=1268 on 2011-12-17.
31. Diversity estimates based on WoRMS (2011). Echiura. Accessed through: World Register of Marine Species at http://www.marinespecies.org/aphia.php?p=taxdetails&id=1269 on 2011-12-17.
32. Based on Noordijk et al. (2010) with updates of 2010 and 2011 new names in Zoological Record.
33. Based on Chapman (2009).
34. Based on WoRMS (2011). Brachiopoda. In: Emig, C.C. (Ed) (2011). World Brachiopoda database. Accessed through: World Register of Marine Species at http://www.marinespecies.org/aphia.php?p=taxdetails&id=1803 on 2011-12-18.
35. See Emig (2011, this volume).

Phylum 2.2.2.3.3.2.3.3.1 **Gastrotricha** Metschnikoff, 1864 (790 species)[36]

Phylum 2.2.2.3.3.2.3.3.2 **Platyhelminthes** Gegenbaur, 1859 (29,285 species)[37]

Phylum 2.2.2.3.3.2.3.3.3.1 **Gnathostomulida** Riedl, 1969 (109 species)[38]

Phylum 2.2.2.3.3.2.3.3.3.2 **Micrognathozoa** Kristensen & Funch, 2000 (1 species)[39]

Phylum 2.2.2.3.3.2.3.3.3.3.1 **Rotifera** Cuvier, 1817 (1,583 species)[40]

Phylum 2.2.2.3.3.2.3.3.3.3.2 **Acanthocephala** Koelreuther, 1771 (1,194 species, of which †2)[41]

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37. Seth Tyler (Personal communication)
38. Based on WoRMS (2011). Gnathostomulida. Accessed through: World Register of Marine Species at http://www.marinespecies.org/aphia.php?p=taxdetails&id=14262 on 2011-12-17.
39. Based Kristensen & Funch (2000), who originally proposed it as a class.
40. Segers (2011, this volume).
41. Edgecombe *et al.* (2011) subsumed this phylum into Rotifera, however, specialists of Ritifera and Acanthocephala have not yet fully accepted this (Segers 2011 & Monks 2011, this volume). Diversity estimate and classification, see Monks (2011).

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